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Renewable energy and sustainable development: a crucial review

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Abstract

Achieving solutions to environmental problems that we face today requires long-term potential actions for sustainable development. In this regard, renewable energy resources appear to be the one of the most efficient and effective solutions. That is why there is an intimate connection between renewable energy and sustainable development. Anticipated patterns of future energy use and consequent environmental impacts (focussing on acid precipitation, stratospheric ozone depletion and the greenhouse effect) are comprehensively discussed in this paper. Also, potential solutions to current environmental problems are identified along with renewable energy technologies. The relations between renewable energy and sustainable development are described with practical cases, and an illustrative example is presented. Throughout the paper several issues relating to renewable energy, environment and sustainable development are examined from both current and future perspectives. It is believed that the conclusions and recommendations drawn in the present study will be useful to energy scientists and engineers and policy makers. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Energy is the convertible currency of technology. Without energy the whole fabric of society as we know it would crumble; the effect of a 24-h cut in

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electricity supplies to a city shows how totally dependent we are on that particularly useful form of energy. Computers and lifts cease to function, hospitals sink to a care and maintenance level and the lights go out. As populations grow, many faster than the average 2%, the need for more and more energy is exacerbated. Enhanced lifestyle and energy demand rise together and the wealthy industrialized economies which contain 25% of the world's population consume 75% of the world's energy supply [1].

Problems with energy supply and use are related not only to global warming, but also to such environmental concerns as air pollution, acid precipitation, ozone depletion, forest destruction, and emission of radioactive substances. These issues must be taken into consideration simultaneously if humanity is to achieve a bright energy future with minimal environmental impacts. Much evidence exists, which suggests that the future will be negatively impacted if humans keep degrading the environment.

Other environmental considerations have been given increasing attention by energy industries and the public. The concept that consumers share responsibility for pollution and its cost has been increasingly accepted. In some jurisdictions, the prices of many energy resources have increased over the last one to two decades, in part to account for environmental costs. World population is expected to double by the middle of the 21st century [2], and economic development will almost certainly continue to grow. Global demand for energy services is expected to increase by as much as an order of magnitude by 2050, while primary-energy demands are expected to increase by 1.5–3 times [2]. Simultaneously, concern will likely increase regarding energy-related environmental concerns such as acid precipitation, stratospheric ozone depletion and global climate change.

One solution to the impending energy shortage is to make much more use of renewable energy sources and technologies. This cause is sometimes espoused with a fervor which leads to extravagant and impossible claims being made. Engineering practicality, reliability, applicability, economy, scarcity of supply and public acceptability should all be considered accordingly.

Ultimately, of course, all energy supplies on Earth derive from the sun and solar energy provides a continuous stream of energy which warms us, causes crops to grow via photosynthesis, heats the land and sea differentially and so causes winds and consequently waves and, of course, rain leading to hydropower. Tidal rise and fall is the result of gravitational pull of moon and sun and geothermal heat the result of radioactive decay deep in the Earth. All are possible sources of energy but though the science is understood, it does not follow that provided enough research money is poured into the project an engineering solution should be found appropriately [1]. The scientific understanding of the process is the easy part; it is the engineering that is difficult to conduct.

In the light of preceding explanations we can point out the fact that energy is one of the main factors that must be considered in discussions of sustainable development. Several definitions of sustainable development have been put forth, including the following common one: "development that meets the needs of the present without compromising the ability of future generations to meet their own

needs" [3]. There are many factors that can contribute to achieving sustainable development. One of the most important is the requirement for a supply of energy resources that is fully sustainable [4–7]. A secure supply of energy resources is generally agreed to be a necessary but not sufficient requirement for development within a society. Furthermore, sustainable development within a society demands a sustainable supply of energy resources (that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts) and an effective and efficient utilization of energy resources. In this regard, the intimate connection between renewable energy sources and sustainable development comes out.

The main objective of this paper is to discuss the environmental problems such as acid precipitation, stratospheric ozone depletion, and greenhouse effect and the anticipated patterns of future energy use and consequent environmental impacts and to identify some solutions to the current environmental problems, focussing on renewable energy sources and technologies and the linkage between renewable energy and sustainable development.

2. Environmental problems

During the past two decades the risk and reality of environmental degradation have become more apparent. Growing evidence of environmental problems is due to a combination of several factors since the environmental impact of human activities has grown dramatically because of the sheer increase of world population, consumption, industrial activity, etc. Throughout the 1970 s most environmental analysis and legal control instruments concentrated on conventional pollutants such as SO_2, NO_x, particulates, and CO. Recently environmental concern has extended to the control of micro- or hazardous air pollutants, which are usually toxic chemical substances and harmful in small doses, as well as to that of globally significant pollutants such as CO_2. Aside from advances in environmental science, developments in industrial processes and structures have led to new environmental problems. For example, in the energy sector, major shifts to the road transport of industrial goods and to individual travel by cars has led to an increase in road traffic and hence a shift in attention paid to the effects and sources of NO_x and volatile organic compound (VOC) emissions. A detailed information on these gaseous and particulate pollutants and their impacts on the environment and human bodies has been recently presented by Dincer [8].

Environmental problems span a continuously growing range of pollutants, hazards and ecosystem degradation over ever wider areas. The major areas of environmental problems may be classified as follows:

- Major environmental accidents
- Water pollution
- Maritime pollution

- Land use and siting impact
- Radiation and radioactivity
- Solid waste disposal
- Hazardous air pollutants
- Ambient air quality
- Acid rain
- Stratospheric ozone depletion, and
- Global climate change (greenhouse effect).

Among these environmental issues, the internationally known most vital problems are the acid precipitation, the stratospheric ozone depletion, and the global climate change. In conjunction with this, we will focus on these three concerns in detail. Before commencing, it is useful to provide a scheme of the pollutants and their environmental impacts as tabulated in Table 1.

2.1. Acid rain

This is a form of pollution depletion in which pollutants produced by the combustion of fossil fuels, particularly from both stationary and mobile sources such as smelters for nonferrous ores, industrial boilers, and transportation vehicles, are transported over great distances through the atmosphere and deposited via precipitation on the Earth on ecosystems that are exceedingly vulnerable to damage from excessive acidity. This acid rain deposition was found to be mainly attributable to emissions of SO_2 and NO_x [8] and such gases react with water and oxygen in the atmopshere and result in acids such as sulfuric and nitric acids (Fig. 1). It is therefore obvious that the solution to the issue of acid rain deposition requires an appropriate control of SO_2 and NO_x.

The pollutants have caused only local concerns related to health in the past. However, as awareness of their contributions to the regional and transboundary problem of acid precipitation has grown, attention has begun also focusing on other substances such as volatile organic compounds (VOCs), chlorides, ozone and trace metals that may participate in the complex set of chemical transformations in the atmosphere resulting in acid precipitation and the formation of other regional air pollutants. There are a number of major evidences to show the damages of acid precipitation as follows [7]:

- Acidification of lakes, streams and ground waters
- Toxicity to plants from excessive acid concentration
- Resulting in damage to fish and aquatic life
- Damage to forests and agricultural crops
- Deterioration of materials, e.g., buildings, metal structures and fabrics
- Influence of sulfate aerosols on physical and optical properties of clouds.

It is obvious that some energy-related activities are major sources of acid precipitation. For example, electric power generation, residential heating and industrial energy use account for 80% of SO_2 emissions, with coal use alone

Table 1
Main gaseous pollutants and their impacts on the environment[a]

Gaseous pollutant	Greenhouse effect	Stratospheric ozone depletion	Acid precipitation	Smog
Carbon monoxide (CO)				
Carbon dioxide (CO_2)	+	±		
Methane (CH_4)	+	±		
Nitric oxide (NO) and nitrogen dioxide (NO_2)		±	+	+
Nitrous oxide (N_2O)	+	±		
Sulfur dioxide (SO_2)	−	+		
Chlorofluorocarbons (CFCs)	+	+		
Ozone (O_3)	+			+

[a] Where + stands for positive contribution, and − stands for variation with conditions and chemistry, may not be a general contributor; *source*, Ref. [17].

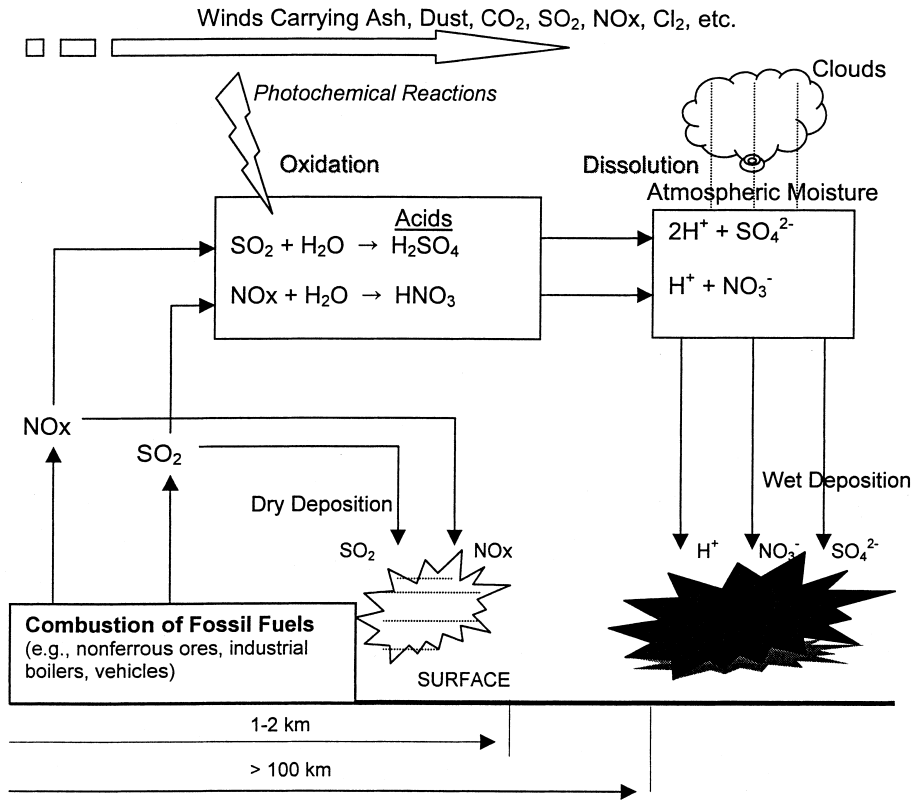

Fig. 1. A schematic representation of the formation, distribution, and impact of acid precipitation.

accounting for about 70% of SO_2 emissions. Another source of acid precipitation is sour gas treatment which produces H_2S that reacts to form SO_2 when exposed to air. Road transport is an important source of NO_x emissions, accounting for 48% of the total in OECD countries [9]. Most of the remaining NO_x emissions are due to fossil fuel combustion in stationary sources. Additionally, VOCs are generated by a variety of sources, and comprise a large number of diverse compounds. Of course, countries in which the energy-related activities occur widely are likely to be significant contributors to acid precipitation. The largest contributors in the world are the United States, countries from the former Soviet Union, and China [2].

As mentioned earlier, acid rain exerts its deleterious effects on the ecology of water systems, on forests, and on historical and cultural artifacts. The acid rain produced by some countries' emissions often happens to fall on other countries. The problem was underrated until the evidence of its importance became overwhelming. That is why this problem is very complex. This complexity makes it difficult to apply the principle of "the polluter pays", and has already led to

some acrimony between governments. Coal and high-sulphur fuel oil are the main contributing sources to acid precipitation and considerable research is therefore being undertaken on "clean coal technologies". Possible methods to reduce the acid gas emissions attributable to these fuels include cleaning the coal before combustion, as well as burning it more cleanly through the use of such techniques as fluidized bed combustion technology. Other major contributors to acid precipitation are the transport vehicles and their contributions will likely continue to increase. Three-way catalytic converters can reduce the emissions of some pollutants but, unfortunately, they increase the quantity of fuel consumed and hence the amount of carbon dioxide released into the atmosphere. Some well understood and effective measures for controlling acid precipitation include limiting the number of vehicles through promoting efficient public transport, and encouraging or enforcing the use of more fuel-efficient vehicles.

2.2. Stratospheric ozone depletion

It is well known that the ozone present in the stratosphere, roughly between altitudes of 12 and 25 km, plays a natural, equilibrium-maintaining role for the Earth, through absorption of ultraviolet (UV) radiation (240–320 nm) and absorption of infrared radiation [8]. A global environmental problem is the distortion and regional depletion of the stratospheric ozone layer which has been shown to be caused by the emissions of CFCs, halons (chlorinated and brominated organic compounds) and NO_x (Fig. 2). Ozone depletion in the stratosphere can lead to increased levels of damaging ultraviolet radiation reaching the ground, causing increased rates of skin cancer, eye damage and other harm to many biological species.

Energy- and non-energy related activities are only partially (directly or indirectly) responsible for the emissions which lead to stratospheric ozone depletion. CFCs, which are used in air conditioning and refrigerating equipment as refrigerants and in foam insulation as blowing agents, and NO_x emissions which are produced by fossil fuel and biomass combustion processes, natural denitrification, nitrogen fertilizers, and aircrafts play the most significant role in ozone depletion. Though scientific debate on ozone depletion has occurred for over a decade, only in 1987 was an international landmark protocol signed in Montreal to reduce the production of CFCs and halons. Conclusive scientific evidence of the destruction of stratospheric ozone by CFCs and halons has recently been gathered, and commitments for more drastic reductions in their production were undertaken at the 1990 London Conference [10]. Tuck [11] undertook a comprehensive study on the current status of stratospheric ozone including a number of aspects such as historical review of the problem, chemical and physical phenomena of the ozone depletion, ozone losses in the stratosphere by giving some maps and the hypotheses on these impacts, and some crucial concluding remarks.

Replacement equipment and technologies that do not use CFCs are gradually coming to the fore and may ultimately allow for a total ban of CFCs. An

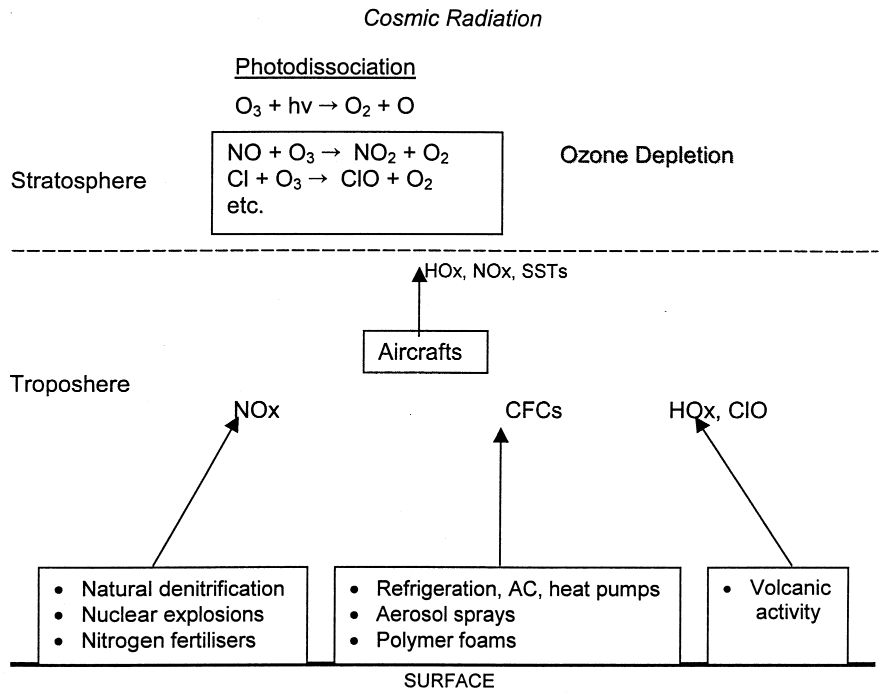

Fig. 2. A schematic representation of sources of natural and anthropogenic ozone depleters.

important consideration in such a CFC ban is the need to distribute fairly the economic burdens deriving from the ban, particularly with respect to developing countries, some of which have invested heavily in CFC-related technologies. In order to eliminate or minimize the impacts of the NO_x emissions, the solutions mentioned in the previous section can be implemented accordingly.

2.3. Global climate change (greenhouse effect)

Although the term *greenhouse effect* has generally been used for the role of the whole atmosphere (mainly water vapor and clouds) in keeping the surface of the Earth warm, it has been increasingly associated with the contribution of CO_2 (currently, it is estimated that CO_2 contributes about 50% to the anthropogenic greenhouse effect). However, several other gases such as CH_4, CFCs, halons, N_2O, ozone and peroxyacetylnitrate (so-called *greenhouse gases*) produced by industrial and domestic activities can also contribute to this effect, resulting in a rise in the Earth's temperature (Fig. 3).

Potentially the most important environmental problem relating to energy utilization is the greenhouse effect, also known as global warming. Increasing atmospheric concentrations of greenhouse gases are increasing the manner in which these gases trap heat radiated from the Earth's surface, thereby raising the

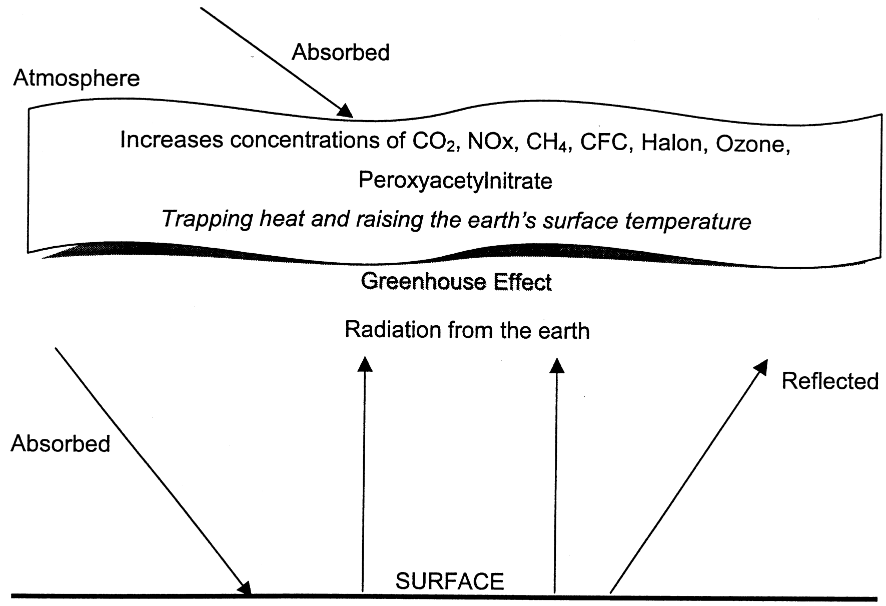

Fig. 3. A schematic representation of greenhouse effect.

surface temperature of the Earth. The Earth's surface temperature has increased about 0.6°C over the last century, and as a consequence sea level is estimated to have risen by perhaps 20 cm [12]. Such changes can have wide-ranging effects on human activities all over the world. Current knowledge of the role of various greenhouse gases is summarized in Dincer and Rosen [7]. Humankind is contributing through many of its economic and other activities to the increase in the atmospheric concentrations of various greenhouse gases. For example, CO_2 releases from fossil fuel combustion, methane emissions from increased human activity, CFC releases and deforestation all contribute to the greenhouse effect. Most scientists agree that there is a cause–effect relationship between the observed emissions of greenhouse gases and global warming. Furthermore, many scientists predict that if atmospheric concentrations of greenhouse gases continue to increase, as present trends in fossil fuel consumption suggest will occur, the Earth's temperature may increase in the next century by another 2°C and perhaps by up to 4°C. If this prediction is realized, sea level could rise between 30 and 60 cm before the end of the 21st century [12]. The impact of such a phenomenon could be dramatic, including flooding of coastal settlements, a displacement of fertile zones for agriculture and food production toward higher latitudes, and a decreasing availability of fresh water for irrigation and other essential uses. Such consequences could jeopardize the survival of entire populations.

Crucial to discussions on averting global climate change is thorough evaluations of the costs of reducing carbon emissions. From a developing-country perspective, the discussion of costs and benefits has to take into account the need for policies

promoting rapid economic growth. Achieving such a balance between economic development and emissions abatement requires the adoption of domestic policies aimed at improving the efficiency of energy use and facilitating fuel switching, and the implementation of international policies enabling easier access to advanced technologies and external resources.

The arguments about the magnitude of greenhouse effect have ranged back and forth for some time. There are those who believe that the Earth is doomed to a rise in temperature and there are those who believe that we can go on polluting the atmosphere without consequence. Whatever the argument, there is no doubt that the emissions are harmful and destroy the environment [13]. Of course, there are several contradictory reports and arguments published recently that make this field complicated to study. Furthermore, the environment should be considered to be an extremely limited resource, and discharge of chemicals into it should be subject to severe constraints. Nevertheless, in order to conduct a successful environmental study we should have a clear outline and include the following significant steps:

- Definition of the main goals both short- and long-term
- Measurement or estimation of the data needed as accurately as possible
- Evaluation of the measurements or estimations
- Generation of new and reliable data
- Reporting of the results without outraging.

3. Potential solutions to environmental problems

Recently, some potential solutions to the current environmental problems associated with the harmful pollutant emissions have evolved, including:

- Renewable energy technologies
- Energy conservation (efficient energy utilization)
- Cogeneration and district heating
- Energy storage technologies
- Alternative energy dimensions for transport
- Energy source switching from fossil fuels to environmentally benign energy forms
- Coal cleaning technologies
- Optimum monitoring and evaluation of energy indicators
- Policy integration
- Recycling
- Process change and sectoral shiftment
- Acceleration of forestation
- Carbon or fuel taxes
- Materials substitution
- Promoting public transport

- Changing life styles
- Increasing public awareness
- Education and training.

Among the potential solutions listed, we will discuss the most important one, the renewable energy technologies, in the following section.

4. Renewable energy resources and technologies

Since the oil crises in the early 1970 s, there has been active worldwide research and development in the field of renewable energy resources and systems. During this time, energy conversion systems that were based on renewable energy technologies appeared to be most attractive because of facts such as the projected high cost of oil and the cost effectiveness estimates and easy implementation of renewable energy systems. Furthermore, in more recent times, it has been realized that renewable energy sources and systems can have a beneficial impact on the following essential technical, environmental, economic, and political issues of the world [14]:

- Major environmental problems (e.g., acid rain, stratospheric ozone depletion, greenhouse effect)
- Environmental degradation
- Depletion of the world's nonrenewable energy sources
- Increasing energy use in developing countries.

As pointed out by Hartley [15], renewable energy technologies produce marketable energy by converting natural phenomena into useful energy forms. These technologies use the energy inherent in sunlight and its direct and indirect impacts on the Earth (photons, wind, falling water, heating effects, and plant growth), gravitational forces (the tides), and the heat of the Earth's core (geothermal) as the resources from which they produce energy. These resources represent a massive energy potential which dwarfs that of equivalent fossil resources. Therefore, the magnitude of these is not a key constraint on energy production. However, they are generally diffuse and not fully accessible, some are intermittent, and all have distinct regional variabilities. Such aspects of their nature give rise to difficult, but solvable, technical, institutional, and economical challenges inherent in development and use of renewable energy resources. Despite having such difficulties and challenges, the research and development on renewable energy resources and technologies has been expanded during the past two decades because of the facts listed above. Nowadays, significant progress is made by:

- Improving the collection and conversion efficiencies
- Lowering the initial and maintenance costs
- Increasing the reliability and applicability
- Understanding the phenomena of renewable energy systems.

Table 2 gives the renewable energy technologies as a mix of several old concepts (e.g., hydropower, geothermal, biomass) and new technologies (e.g., solar, ocean thermal).

Renewable energy technologies become important as environmental concerns increase, utility (hydro) costs climb and labor costs escalate [16]. The uncertain global economy is an additional factor. The situation may be turned around with an increase in research and development in the Hi-Tech fields, some of which are closely associated with renewable energy technologies. This may lead to innovative products and job creation that are supported by the governments. The progress in other technologies, especially in Hi-Tech has induced some innovative ideas in renewable energy system designs. The ubiquitous computer has provided means for optimizing system performance, costs/benefits and environmental impacts even before the engineer was off the drawing board!

The operating and financial attributes of renewable energy technologies, which include modularity and flexibility, low operating costs (suggesting relative cost certainty), are considerably different than those for traditional, fossil based technologies, whose attributes include large capital investments, long implementation lead times, and operating cost uncertainties, regarding future fuel costs. The overall benefits of renewable energy technologies are often not well understood and consequently they are often evaluated to be not as cost effective as traditional technologies. In order to assess comprehensively renewable energy technologies, however, some of their benefits that are often not considered must be accounted for. Renewable energy technologies, in general, are sometimes seen as direct substitutes for existing technologies so that their benefits and costs are

Table 2
Maturity of renewable energy technologies (*source*, Ref. [15])

Proven capability Hydropower	Transition phase Wind	Future potential Advanced Turbines
Geothermal	Geothermal	Geothermal
Hydrothermal	Hydrothermal	Hot dry rock
		Geopressure
		Magma
Biomass	Biofuels	Biofuels
Direct combustion	Ethanol from corn	Methane
Gasification	Municipal wastes	
Passive solar	Active solar	Solar thermal
Buildings	Buildings	Advanced electricity
	Process heat	High-temperature processes
	Solar Thermal	
	Thermal/gas hybrid	
Photovoltaics	Photovoltaics	Photovoltaics
Small remote	Remote power	Utility power
Specialty products	Diesel hybrids	
		Ocean Thermal

conceived in terms of assessment methods developed for the existing technologies. For example, solar and other renewable energy technologies can provide small incremental capacity additions to the existing energy systems with short lead times. Such power generation units usually provide more flexibility in incremental supply than large, long lead-time units such as nuclear power stations.

For the 1990 s, some of the well-tried renewable energy technologies that have been tested for years in the field will continue to expand with improved designs. The market demand for them by the developing nations will grow as they seek a better standard of living. The impact of global use of renewable energy systems will certainly reduce the pollution levels. During the past two decades, a tremendous progress has been made on the solar energy technologies, particularly in photovoltaics (PV). Solar photovoltaic energy, the direct conversion of sunlight into electric power by a solid-state device, has progressed rapidly since the launch of the first satellite in the 1950 s. The impetus was due to the ubiquitous silicon *chip* technology in the United States, Japan and Germany that has spawned the world's electronic industries leading to the super *highways* on communications. Now, large terrestrial photovoltaic power stations, some about 100 MW capacity, feed the AC grid network or operate as stand-alone in the United States. Let us compare it with hydro generated power; for example, the energy costs in the United States are $0.06 to 0.20/kWh for hydro and $0.30 to 0.40/kWh for PV [18].

Development of advanced renewable energy technologies can serve as cost-effective and environmentally responsible alternatives to conventional energy generation. Technical and market potential exists to significantly increase the current contribution of renewable energy sources to country's energy demands by the year 2000, resulting in employment and economic benefits many times the R&D investment. Many government energy institutions and agencies recognize this opportunity and support their renewable energy industry's efforts to exploit near-term commercial potential by [16]:

- Analyzing opportunities for renewable energy and working in consultation with industry to identify R&D and market strategies to meet technological goals
- Conducting R&D in cooperation with industry to develop and commercialize technologies
- Encouraging the application of renewable energy technologies to potential users, including utilities
- Providing technical support and advice to industry associations and government programs that are encouraging the increased use of renewable energy.

In order to realize the energy, economic and environmental benefits that renewable energy sources offer, the following integrated set of activities should be acted on accordingly:

- *Research and development*: R&D priorities should be set in close consultation with industry to reflect their needs. Most research is conducted through cost-shared agreements and falls within the short-to-medium term. Partners in R&D

should include a variety of stakeholders in the energy industry, such as private sector firms, utilities across the country, provincial governments and other federal departments.

- *Technology assessment*: Data should be gathered in the lab and through field trials on factors such as cost benefit, reliability, environmental impact, safety and opportunities for improvement. These data should also assist the preparation of technology status overviews and strategic plans for R&D.
- *Standards development*: The development of technical and safety standards is needed to encourage the acceptance of proven technologies in the marketplace. Standards development should be conducted in cooperation with national and international standards writing organizations, as well as other national and provincial regulatory bodies.
- *Technology transfer*: R&D results should be transferred through sponsorship of technical workshops, seminars and conferences, as well as through the development of training manuals and design tools, and the publication of technical reports.

Such activities will also encourage potential users to consider the benefits of adopting renewable energy technologies. In support of developing near-term markets, a key technology transfer area is to accelerate the use of renewable energy technologies in a country's remote communities.

4.1. Illustrative example

Here, we present a case study performed by the city of Saarbrucken in Germany which has 180,000 inhabitants. It started implementing a new energy and environment strategy in the 1980 s in order to reduce energy consumption and CO_2 emissions mainly by undertaking the following actions: (i) advice and information, (ii) least cost planning, (iii) district heating, (iv) seasonal energy storage, and, the most important, (v) maximizing the use of renewable energies by undertaking several actions including:

- Passive solar energy was promoted through advice to architects, planners, etc
- Four outdoor swimming pools were heated with active solar systems
- The 1000 kW *solar roof programme* for photovoltaic solar energy was initiated and more than one-third has been installed
- For hydropower a 1 MW installation was planned and a significant amount of energy is now coming from this source.

Their achievements from 1980 to 1990 can be listed as follows:

- A 15% reduction in heating demand for the entire city
- A 45% reduction in heating consumption for the municipal buildings
- A 15% reduction in CO_2 emissions from heating and electrical requirements of the municipality.

As is evident from this illustrative example, the city Saarbrucken implemented a

successful energy program and, as a result, received a Local Government Honor at the *United Nations Conference on Environment and Development* in Rio de Janeiro in June 1992 [19].

5. Sustainable development

A secure supply of energy resources is generally agreed to be a necessary but not sufficient requirement for development within a society. Furthermore, sustainable development demands a sustainable supply of energy resources that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts. Supplies of such energy resources as fossil fuels (coal, oil, and natural gas) and uranium are generally acknowledged to be finite; other energy sources such as sunlight, wind and falling water are generally considered renewable and therefore sustainable over the relatively long term. Wastes (convertible to useful energy forms through, for example, waste-to-energy incineration facilities) and biomass fuels are also usually viewed as sustainable energy sources. In general, the implications of these statements are numerous, and depend on how sustainable is defined [7].

Environmental concerns are an important factor in sustainable development. For a variety of reasons, activities which continually degrade the environment are not sustainable over time, e.g., the cumulative impact on the environment of such activities often leads over time to a variety of health, ecological and other problems. A large portion of the environmental impact in a society is associated with its utilization of energy resources. Ideally, a society seeking sustainable development utilizes only energy resources which cause no environmental impact (e.g., which release no emissions to the environment). However, since all energy resources lead to some environmental impact, it is reasonable to suggest that some (not all) of the concerns regarding the limitations imposed on sustainable development by environmental emissions and their negative impacts can be in part overcome through increased energy efficiency. Clearly, a strong relation exists between energy efficiency and environmental impact since, for the same services or products, less resource utilization and pollution is normally associated with increased energy efficiency.

While not all renewable energy resources are inherently clean, there is such a diversity of choices that a shift to renewables carried out in the context of sustainable development could provide a far cleaner system than would be feasible by tightening controls on conventional energy. Furthermore, being by nature site-specific, they favor a power system decentralization and locally applicable solutions more or less independent of the national network. It enables citizens to perceive positive and negative externalities of energy consumption. Consequently, the small scale of the equipment often makes the time required from initial design to operation short, providing greater adaptability in responding to unpredictable growth and/or changes in energy demand.

5.1. Importance of renewable energy resources and technologies for sustainable development

The exploitation of renewable energy resources and technologies is a key component of sustainable development [19]. There are three significant reasons for it as follows.

1. They have much less environmental impact compared to other sources of energy since there is no any energy sources with zero environmental impact. There are a variety of choices available in practice that a shift to renewables could provide a far cleaner energy system than would be feasible by tightening controls on conventional energy.
2. Renewable energy resources can not be depleted unlike fossil fuel and uranium resources. If used wisely in appropriate and efficient applications, they can provide a reliable and sustainable supply energy almost indefinitely. In contrast, fossil fuel and uranium resources are finite and can be diminished by extraction and consumption.
3. They favor power system decentralization and locally applicable solutions more or less independent of the national network, thus enhancing the flexibility of the system and the economic power supply to small isolated settlements. That is why many different renewable energy technologies are potentially available for use in urban areas.

5.2. Essential factors for sustainable developments

The main concept of sustainability, which often inspires local and national authorities to incorporate environmental considerations in setting energy programmes, though being given many different meanings in different contexts, embodies a long-term perspective. Besides, the future energy system will be largely shaped by broad and powerful trends that have their roots in basic human needs. In conjunction with this, the increasing world population requires the definition and successful implementation of sustainable development. There are various essential parameters that can help in achieving a successful sustainable development in a society. Such parameters can be described as follows:

- *Public awareness*: This is the initial step and very crucial in making the sustainable energy program successful. This should be carried out through the media and by public and/or professional organizations.
- *Information*: Necessary informational input on energy utilization, environmental impacts, renewable energy resources, etc. should be provided to public through public and government channels.
- *Environmental education and training*: This can be implemented as a completing part of the information. Any approach which does not have an integral education and training is likely to fail. That is why this can be considered as the

significant prerequisite for a sustainable energy program. For this reason, a wide scope of specialized agencies and training facilities should be made available to the public.

- *Innovative energy strategies*: These should be provided for an effective sustainable energy program and, therefore, require the efficient dissemination of information, based on new methods and consisting of public relations, training and counseling.
- *Promoting renewable energy resources*: In order to achieve environmentally benign sustainable energy programs, renewable energy sources should be promoted in every stage. This will create a strong basis for the short- and long-term policies.
- *Financing*: This is a very important tool that can be used for reaching the main goal and will accelerate the implementation of renewable energy systems and technologies for sustainable energy development of the country. Some countries, e.g., Germany, apply the support a different way and simply exempt the people who use such systems and technologies from some portion of their taxes.
- *Monitoring and evaluation tools*: In order to see how successfully the program has been implemented, it is of great importance to monitor each step and evaluate the data and findings obtained. In this regard, appropriate monitoring and evaluation tools should be used.

6. Conclusions

Renewable energy resources and their utilization are intimately related to sustainable development. For societies to attain or try to attain sustainable development, much effort should be devoted to discovering sustainable energy resources in terms of renewables. In addition, environmental concerns should be addressed. The following concluding remarks can be drawn from this study:

- There are a number of environmental problems that we face today. These problems span a continuously growing range of pollutants, hazards and ecosystem degradation over ever wider areas. The most significant ones are acid precipitation, stratospheric ozone depletion, and global climate change.
- Potentially the most important environmental problem relating to energy utilization is the greenhouse effect. Increasing atmospheric concentrations of greenhouse gases are increasing the manner in which these gases trap heat radiated from the Earth's surface, thereby raising the surface temperature of the Earth and as a consequence risen sea levels.
- Recently, a variety of potential solutions to the current environmental problems associated with the harmful pollutant emissions has evolved. However, renewable energy appears to be one of the most important solutions.
- Renewable energy technologies, in general, are sometimes seen as direct substitutes for existing technologies so that their benefits and costs are

conceived in terms of assessment methods developed for the existing technologies. For example, solar and other renewable energy technologies can provide small incremental capacity additions to the existing energy systems with short lead times. Such power generation units usually provide more flexibility in incremental supply than large, long lead-time units such as nuclear power stations.

- Development of advanced renewable energy technologies that serve as cost-effective and environmentally responsible alternatives to conventional energy generation. Technical and market potential exists to significantly increase the current contribution of renewable energy sources to country's energy demands by the year 2000, resulting in employment and economic benefits many times the R&D investment. Many government energy institutions and agencies recognize this opportunity and support their renewable energy industry's efforts to exploit near-term commercial potential.
- In order to attain the energy, economic and environmental benefits that renewable energy sources offer, an integrated set of activities such as R&D, technology assessment, standards development and technology transfer should be conducted as required.
- Sustainable development demands a sustainable supply of energy resources that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts. Supplies of such energy resources as fossil fuels (coal, oil, and natural gas) and uranium are generally acknowledged to be finite; other energy sources such as sunlight, wind and falling water are generally considered renewable and therefore sustainable over the relatively long term.
- The exploitation of renewable energy resources and technologies is a key component of sustainable development due to the facts: (i) much less environmental impact, (ii) more flexibility, (iii) being undepleted, and (iv) decentralization possibility.
- Increasing world population requires the definition and successful implementation of sustainable development.

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